IV-2-1 Introduction

The design of intersections and roadways requires the consideration of the multitude of users who will potentially use the facilities. This involves addressing the needs of a diverse mix of user groups including passenger vehicles, heavy vehicles of varying classifications, bicycles and pedestrians. Finding a balance between the needs of a diverse group of users may be a challenge. The resulting design is determined through appropriate compromise between potentially competing needs, in order to achieve adequate levels of operation for all users.[1]

The following sections describe the specific considerations that can be associated with roadway and intersection configurations.

IV-2-2 Roadway Design

The roadway is designed to allow traffic to travel safely and at a reasonable speed through the corridor. To do this the desired speed must be selected and the vertical and horizontal alignment designed so that traffic can move comfortably, and is able to avoid any hazards that may be on the roadway at this speed. Lanes need to be wide enough to allow large vehicles to use the roadway without interfering with traffic in adjacent lanes. The following sections detail some of the considerations associated with the design of roadway.

IV-2-2-1 Sight Distance

For safe and efficient operation of a vehicle on a roadway, the driver needs to have adequate sight distance to see the road ahead, as well as to see pedestrians and bicyclists. The required sight distance is controlled by the design speed of the roadway and the specific needs at the location being considered. The sight distance needs are divided into the following types:

Stopping sight distance – The distance needed for a driver to see a hazard, recognize it as a hazard, and safely stop the vehicle. Stopping sight distance is required at all locations, on all roadways. It influences the vertical alignment and the placement of objects on the inside of horizontal curves.

Passing sight distance – The distance that a driver needs to be able to see on a two-lane highway to pass a slower vehicle. It is generally not a consideration on urban roadways.

Decision sight distance – The distance needed for drivers to make decisions at complex locations. It gives the driver more time to make the decision to stop or time to make a maneuver, such as change lanes, without stopping. Decision sight distance is used where there are roadside distractions, information sources competing for the driver’s attention, or a design element that may require an unexpected maneuver (such as a lane reduction).

[1] WSDOT, *Design Manual*, p. 910-3

Intersection sight distance – The distance a driver needs to safely enter or cross another roadway. Intersection sight distances are determined by the type of traffic control at the intersections:

- At uncontrolled intersections, drivers on all legs must be able to see a potentially conflicting vehicle approaching on one of the other legs in time to stop before the intersection.
- Intersections with yield control have similar requirements, except intersection sight distance is only required for the legs with the yield.
- At two-way stop controlled intersections, drivers at the stopping point need to be able to see an approaching vehicle the gap-acceptance distance from the intersection. The gap-acceptance distance (expressed in seconds) is the distance an approaching vehicle must be away, for a driver to be comfortable entering the intersection from a stop. The gap-acceptance times vary with movement (turn or crossing), number of lanes, width of median, and grade.
- At a four-way stop, drivers only need to be able to see the first vehicle stopped at each of the other legs.
- Where traffic is controlled by a traffic signal, the first driver waiting at the light should be able to see the first vehicle stopped at the other legs. This is the same for the left-turn lane, when there is a left-turn signal; when there is not a left turn signal, left-turns are treated the same as left-turns from a major roadway. When right-turn on red is permitted it is treated the same as right-turns at two-way stops.
- For left-turns and U-turns from a major roadway (where traffic control is non-existent in the opposite direction), the sight distance is controlled by the gap-acceptance distance, similar to the two-way stop.

The distance that a driver can see is influenced by the position of the driver above the roadway, the vertical and horizontal distances, the height of the object that needs to be seen, and the size and location of sight obstructions. At intersections, the stopping distance is determined by the distance a driver needs to see to stop at the intersection and by the distance from which a driver must make the decision to stop or enter the intersection.

The urban environment may present a relatively high number of sight distance issues compared to more rural areas, because of the proximity of buildings, trees, and other features to the roadway.

IV-2-2-2 Design Speed

Design speed is the speed used to determine various geometric design features of the roadway, such as vertical and horizontal alignment and sight distance requirements. The design speed is based on the roadway classification, terrain type, and roadside development. It is higher for higher classes in rural areas and is reduced for lower classes, urban areas, and mountainous terrain. Normally it should not be less than the posted speed or the speed of traffic.

A low design speed can reduce the required work to meet the design requirements; however, it will also increase travel times and increase the probability of traffic exceeding the safe speed, reducing the safety of the roadway.

IV-2-2-3 Cross Sections

The roadway cross section includes the following design elements: traveled way, shoulders, auxiliary facilities, median, and roadsides. These elements include the number of lanes, widths, slopes, type of auxiliary facility and median, presence of curb, and any added features on the roadside (for example, drainage or pedestrian facilities).

The traffic volume is the main factor in determining the number of lanes required. Other factors that can control the number of lanes include continuity and flexibility of operation.

Lanes should be wide enough to allow the design vehicle to use them without crowding vehicles in adjacent lanes. Lane width is dependent upon the size of the vehicles that use the roadway, clearance between vehicles, and horizontal alignment.

As a vehicle travels around a curve, the rear wheels track to the inside of the path the front wheels traveled. The amount of this offset depends on the size of the vehicle and the radius of the turn. For example, for a passenger car turning on a 100 ft radius, the offset will be less than 1 ft; while for a large semi truck (with a wheel base of 67 ft from first to last axle) will have an offset of 15 ft. The same truck turning on a 300 ft radius will have an offset reduced to 4 ft.

The cross slope, or crown, strikes a balance between vehicle steering and surface runoff needs. If the slope is too steep, vehicles will have the tendency to drift to the low side of the roadway; if it is flat, rainwater will not run off and might result in standing water.

To maintain the desired design speed, the roadway cross slope is increased, or super-elevated, on curves to overcome part of the centrifugal force that acts on a vehicle. Only part of the centrifugal force is overcome so that the driver can still feel the curve.

The shoulder width is controlled by the functions that the shoulder is to provide. A minimum width is needed to provide clearance and lateral structural support to the roadway. Without the minimum clearance, traffic will move over to get away from roadside objects, such as a curb, with the effect of narrowing the lane. Wider shoulders are needed to allow disabled vehicles to stop out of the through lanes. However, if shoulders are too wide for extended lengths, drivers might begin to use them as lanes, which would degrade safety. The shoulder slope is normally the same as the through lanes.

IV-2-3 Intersection Configurations

An intersection is where two or more roadways cross or join. They are an important part of roadway design because their design is a major contributor to the safety, speed, cost, and capacity of a facility. Each roadway radiating from the common area is called a leg of the intersection. An intersection with two roadways that cross each other has four legs.

Traffic characteristics, human factors, bicyclists and pedestrian needs, physical features, and economics are considered during intersection design. They are designed so that the physical features will minimize possible conflict between vehicles and between vehicles and pedestrians to enhance safety and provide efficient traffic flow. Tradeoffs that may be considered when working to minimize the conflicts between users include sidewalk width vs. lane or shoulder width, and pedestrian crossing distances vs. bicycle lanes.

IV-2-3-1 Intersection Types

The four leg intersection at a common elevation of approximately 90º is the most common type of intersect. Vehicles passing through the intersection might have to share the roadway with vehicles crossing on the other roadway, turning vehicles, and pedestrians. The area that both roadways share has a potential for conflict and a higher crash rate.

Intersections of two roadways with only three legs are either tee (T) intersections or wye (Y) intersections. When the two roadways intersect at approximately 90º, the intersection is a tee intersection. A wye intersection is a three-legged intersection with an angle between minor leg and either of the other two legs that is less than 60º. A tee intersection operates similar to a four-legged intersection; however, with a wye intersection, because of the difficulty turning between legs intersecting at an angle less than 60º, the minor leg normally operates as a one-way merge or diverge.

Four legged intersections with a small angle between two legs are undesirable. As the angle decreases, a number of problems associated with the intersection increase, resulting in a reduction of safety. The area of potential conflict increases; sight distance becomes difficult, drivers have to turn their heads farther and objects in the vehicle or the design of the vehicle can block the view; a larger area is needed for turning, particularly for large trucks; and increases in the crossing times for both vehicles and pedestrians can result. Besides increasing the potential for conflict, this can also increase the time that a vehicle must wait to enter an intersection, degrading traffic operations. Intersections perform best when the legs intersect at near right angles.

Other intersections that can present problems are ones with more than four legs. These intersections will normally have several legs that intersect at small angles resulting in all the issues noted above. Capacity problems arise at signalized intersection with the need for an additional signal phase. This will increase the wait time for vehicles stopped by the signal and reduce capacity.

IV-2-3-2 Traffic Management

Intersection traffic management is the process of moving traffic safely through intersection areas of potential conflict. Traffic control devices, channelization, and physical layout are the major tools used to establish intersection traffic management. There are three objectives to intersection traffic management that can greatly improve intersection operations.

Maximize intersection capacity – Since two or more traffic paths cross, converge, or diverge at intersections, capacity of an intersection is normally less than the roadway between intersections. Solutions such as prohibiting some movements, adding lanes for heavier movements and to separate movements, adding transit facilities, and proper right of way assignment, can increase intersection capacity.

Reduce conflict points – Conflict points are created when traffic paths cross, converge, or diverge. The potential for accidents increases at conflict points. Establishing appropriate controls can reduce the probability of accidents occurring. Pedestrian accident potential can also be reduced by appropriate controls.

Assign right of way – It is usually necessary to assign right of way through the use of traffic control devices to reduce the possibility of two cars attempting to occupy the same space at the same time and to maximize capacity for all users of the intersection. Traffic on major routes is given the right of way over traffic on minor roadway to increase intersection operational efficiency.

Consider non-motorized users – Info needed

IV-2-3-3 Traffic Control Devices

Traffic control devices are signs and signals used to assign right of way. The options for traffic control at intersections are as follows:

- No control;
- Yield control and stop control on the minor roadway;
- All-way stop control; and
- Signal control.

Intersections with no control are appropriate only at low traffic volumes on the lowest functional classification. A driver approaching the intersection must be able to see enough of the other legs to determine if it is safe to cross or turn at the intersection, slow, or stop to yield to another vehicle. Intersections with no control are not appropriate on state routes.

Yield signs assign right of way without requiring the other vehicle to stop. Drivers on the minor roadway approaching a yield sign must be able to see enough of the other legs to determine if it is safe to enter the intersection. If it is safe, the drivers on the minor roadway may proceed without stopping, otherwise they must wait until it is safe to proceed. Traffic on the main roadway may pass through the intersection uninterrupted. Yield signs are most common at the merge of turning roadways at intersections.

Stop control on the minor roadway is the most common intersection control on state routes. Drivers on the minor roadway are required to stop before entering the intersection, check for major roadway traffic, and proceed only when it is safe. Traffic on the main roadway passes through the intersection uninterrupted. Stop signs are not to be used for speed control.

All-way stops require traffic on all legs of the intersection to stop before entering the intersection. All-way stops are used at intersections with approximately equal traffic volumes on the intersecting roadways. Other considerations include the need to control left turn conflicts, the need to control vehicle pedestrian conflicts, and the inability for a driver to see conflicting traffic. All-way stops may also be used as an interim measure when traffic signals are justified.

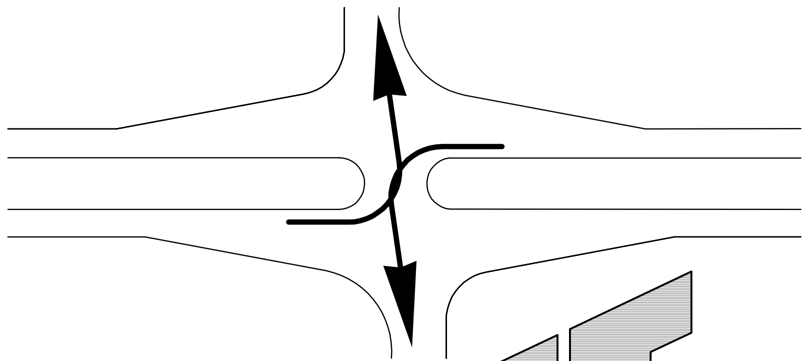
Traffic signals are used to alternate the assignment of right of way to the various movements at an intersection, including pedestrians. When properly designed, located, operated, and maintained, they provide an orderly flow of traffic, increase the capacity of the intersection for all modes, reduce the severity of accidents at the intersection, interrupt heavy traffic to allow cross traffic to use the intersection, and when coordinated with adjacent signals, can provide nearly continuous movement of traffic along a route. When improperly designed, located, operated, and/or maintained, traffic signals can cause excessive delay, increased violation of the signal indications, increased use of other routes to avoid the signal, and increased frequency of traffic accidents.

IV-2-3-4 Channelization

Channelization is the separation of traffic movements into delineated travel paths using pavement markings, curbs, or other suitable means. The main objectives of channelization are to facilitate the orderly movement of vehicles, bicyclists, and pedestrians; improve safety, increase capacity, and maximize convenience. Channelization achieves these objectives with one or more of the following:

- ✓ Separating traffic paths can eliminate unnecessary path overlapping and can segregate movements with different requirements. See Figures IV-2.2 and IV-2.3.
- ✓ Separating conflict points can reduce the probability that a driver will be required to make more than one decision at a time.
- ✓ Reducing the angle between traffic paths at conflict points for merging and diverging can lessen the severity of the conflict.
- ✓ Providing pedestrians mid-block refuge between traffic paths can allow crossing of each traffic movement independently.
- ✓ Protecting and storing turning and crossing vehicles by allowing them to slow or stop clear of other traffic paths can reduce the number and severity of the conflict points.
- ✓ Prohibiting some movements to eliminate conflict points. Only prohibit movements that have a minor demand and have an alternate route.
- ✓ Controlling speeds by building curves or reducing the roadway width to reduce speeds approaching a stop sign or crossing point and to reduce the speed difference between traffic streams that merge.
- ✓ Reducing the pavement area caused by excessive skew and large corner radii might lessen the probability of driver confusion and erratic maneuvers.
- ✓ Installing traffic control devices, such as stop sign and traffic signals, in the optimum position.

Figure IV-2.2 – Unchannelized Left-Turns with Path Overlap



(Source: WSDOT)

Figure IV-2.3 – Channelized Left-Turns without Path Overlap

(Source: WSDOT)

Left- and right-turn lanes are channelization added to improve the efficiency and safety of an intersection by removing the turning vehicles from the through lanes. Left turning drivers frequently must wait for a gap in opposing traffic before completing their turn. A left-turn lane allows the wait to occur outside of the through traffic, reducing delays to through traffic and lessening the probability of a rear end accident. Right-turning vehicles are less likely to be required to stop before completing the turn; however, they can still influence the operation of the intersection. Right-turn lanes allow turning vehicles to complete some or all of their deceleration outside of the through lanes. Turn lanes without adequate storage will impact and reduce through traffic movement capacity

IV-2-3-5 Other Intersection Types

Roundabouts

Modern roundabouts are at-grade, typically circular intersections. They can be an effective intersection design that results in fewer conflict points, lower speeds, and easier decision-making than conventional intersections. Roundabouts generally require less maintenance than traffic signals; and have been found to reduce fatal and severe injury accidents, traffic delays, fuel consumption, and air pollution. They can also have a traffic calming effect. The design of a roundabout forces traffic passing through it to slow. This slowing adds to the reduction in fatal and severe injury accidents. However, it also delays all the traffic passing through the roundabout, even in periods of low volume when there may be no traffic on the cross street.

Traffic passes through a roundabout by merging and diverging with the traffic in the roundabout. This does not form the platoons associated with a traffic signal and traffic will be more evenly distributed. However, the gaps used by traffic at downstream minor intersections to enter or cross the major street are also eliminated.

Lanes are added in a roundabout to increase the capacity. Because of the way traffic passes through the roundabout, added lanes are not needed between the intersections. To add capacity to a signalized intersection, lanes are added to the roadway, normally requiring the roadway between the intersections to be widened also. A roundabout can save the widening between intersections; however, the intersection area can be larger than at a signal.

Figure IV-2.4 Modern Two-lane Roundabout

(Source: City of Lacey, WA)

Modern roundabout design includes a small diameter that constrains circulating speeds; raised splitter islands that slow down entering vehicles; and a yield at entry point, which requires entering vehicles to yield and allow circulating traffic to flow freely.

Roundabouts are generally safer than other forms of intersections. Injury accident rates are generally lower, although the proportion of single-vehicle accidents is typically higher. Bicyclists and pedestrians are also involved in a relatively higher proportion of injury accidents at roundabouts than they are at other intersections. Overall, though, accident rates and severity are lower at roundabouts.

When operating within their design traffic volume, roundabouts normally operate with less vehicle delays than other intersections. With a roundabout, it is unnecessary for traffic to completely stop when no other vehicles are approaching, or when deceleration prevents a conflict. When there are queues, traffic within the queues usually continues to move, and this is typically more tolerable to drivers than a stopped queue. The performance of roundabouts during off-peak periods is particularly good in contrast to other intersection forms, typically with very low average delays.

Roundabouts tend to treat all movements at an intersection equally. Each approach is required to yield to circulating traffic, regardless of whether the approach is a local street or major arterial - all movements are given equal priority. This might result in more delay to the major movements than is desirable.

Roundabouts can provide environmental benefits if they reduce vehicle delay and the number and duration of vehicle stops, in comparison to an alternative intersection design. Even when heavy volumes exist, vehicles within a roundabout continue to advance slowly in moving queues rather than coming to a complete stop. This might reduce noise and air quality impacts and fuel consumption by reducing the number of acceleration/ deceleration cycles and the time spent idling.

Roundabouts usually require more space within the intersection for the circular roadway and central island than traditional intersections, and often have a significant right-of-way impact at the intersection. If a signalized intersection requires long or multiple turn lanes to provide sufficient capacity or storage, a roundabout with similar capacity might require less space on the approaches. As a result, roundabouts might reduce the need for additional right of way on the roadways between intersections, at the expense of additional right of way requirements at the intersections themselves. In urban areas, there are typically signalized intersections at both ramp terminals, requiring additional lanes between the intersections to provide capacity and storage. At interchange ramp terminals, roundabouts at each terminal have been used to reduce the number of lanes crossing the freeway.

Landscaping and other objects placed in the center of the roundabout may reduce visibility and may be considered fixed objects. Take care in the placement of these objects to provide appropriate sight-distances and fixed object offsets.

A roundabout does not have signal equipment that requires power, periodic light bulb and detection maintenance, and signal timing updates. However, depending on the landscaping provided on the central island, splitter islands, and perimeter, roundabouts can have higher landscape maintenance costs.

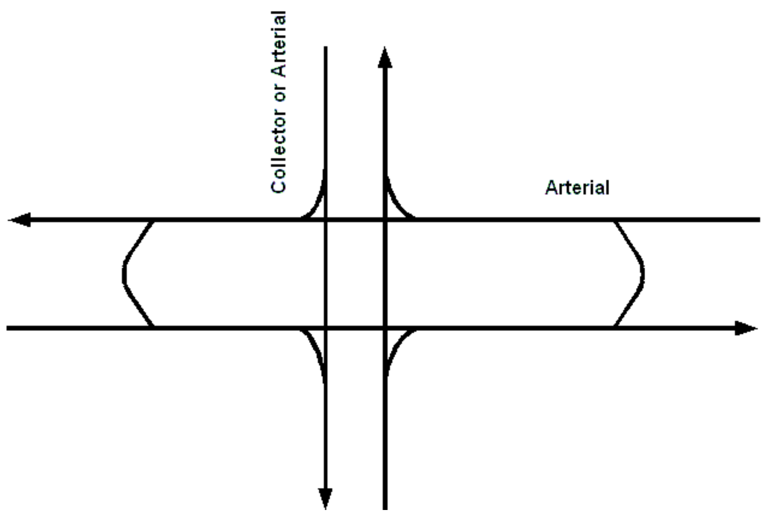
Unique Intersection Types

In addition to roundabouts, there are a number of unique intersection designs that can improve the operation and safety of an intersection. These designs use U-turns, connecting roadways, and grade separations to remove or separate some of the movements. Recognize that these examples are not appropriate in all situations. As with all considerations within this document, evaluate each design characteristic in the context of the specific setting and unique need.

Median U-Turn

At a median U-turn intersection U-turn roadways are constructed a short distance from the intersection on both sides of the intersection. Left-turns are not allowed from either roadway at the intersection. To turn left from the arterial, a vehicle must go through the intersection, make a U-turn at the U-turn roadway, come back to the intersection, and turn right. Left turning traffic from the collector must turn right onto the arterial, proceed to the U-turn roadway, and execute a U-turn. Both of these movements require weaving between the intersection and the U-turn roadway.

Figure IV-2.5 – Median U-Turn

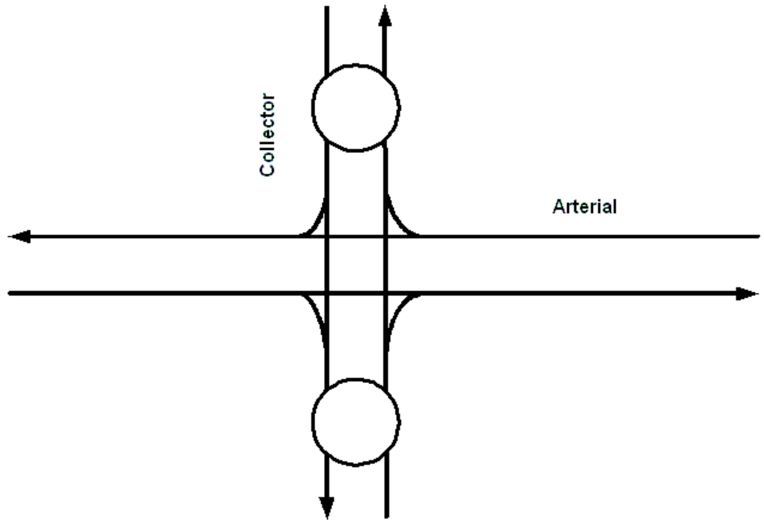


(Source: WSDOT from__)

Bowtie

The bowtie intersection has roundabouts on the collector on each side of the arterial. Like the median U-turn intersection, left-turns are not allowed at the intersection with the arterial. To make a left from the arterial a vehicle must turn right, make a U-turn at the roundabout, and cross the arterial. A vehicle that wants to make a left from the collector must cross the arterial, make a U-turn at the roundabout, and make a right turn at arterial.

Figure IV-2.6 – Bowtie

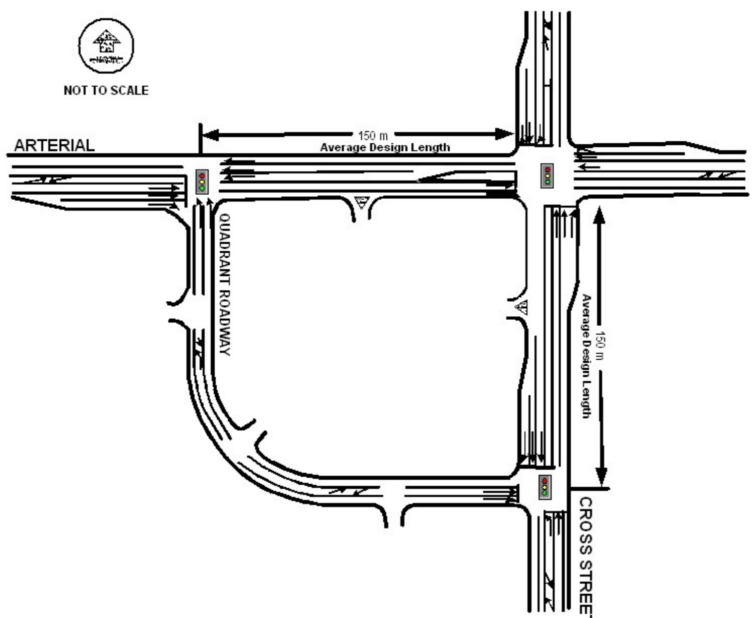


(Source: WSDOT from__)

Quadrant Roadway Intersection (QRI)

The QRI moves the left turns to the quadrant roadway simplifying the intersection. A variation of the QRI separates the two roadways with a grade separation structure with all turning movements using the quadrant roadway.

Figure IV-2.7 – Quadrant Roadway Intersection (QRI)

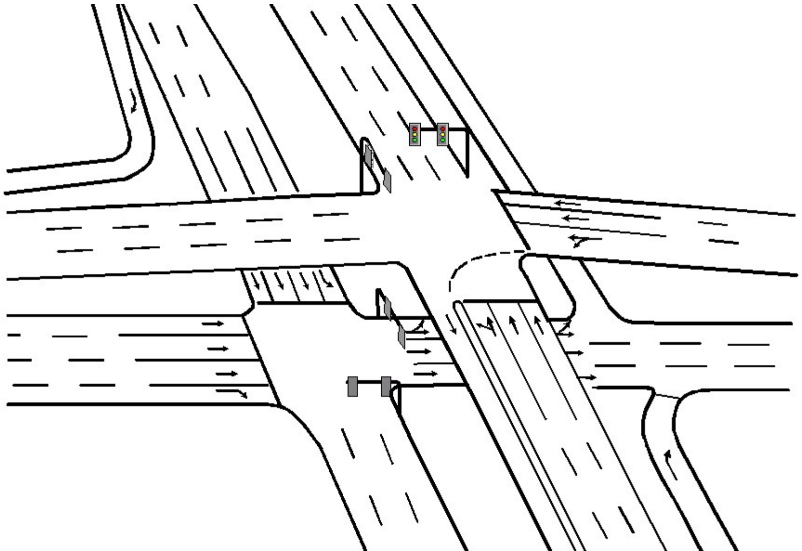


(Source: WSDOT from__)

Echelon Interchange

The echelon interchange uses a structure to separate one-half of each roadway and uses a traffic signal to control the two intersections. All movements at each intersection are unopposed.

Figure IV-2.8 – Echelon Interchange



(Source: WSDOT from__)

Governing Regulations and Directional Documents

Design Manual, WSDOT, M 22-01.

A Policy On Geometric Design of Highways and Streets, 4th ed. (Green Book), American Association of State Highway Transportation Officials, (AASHTO), Washington, D.C., 2001.